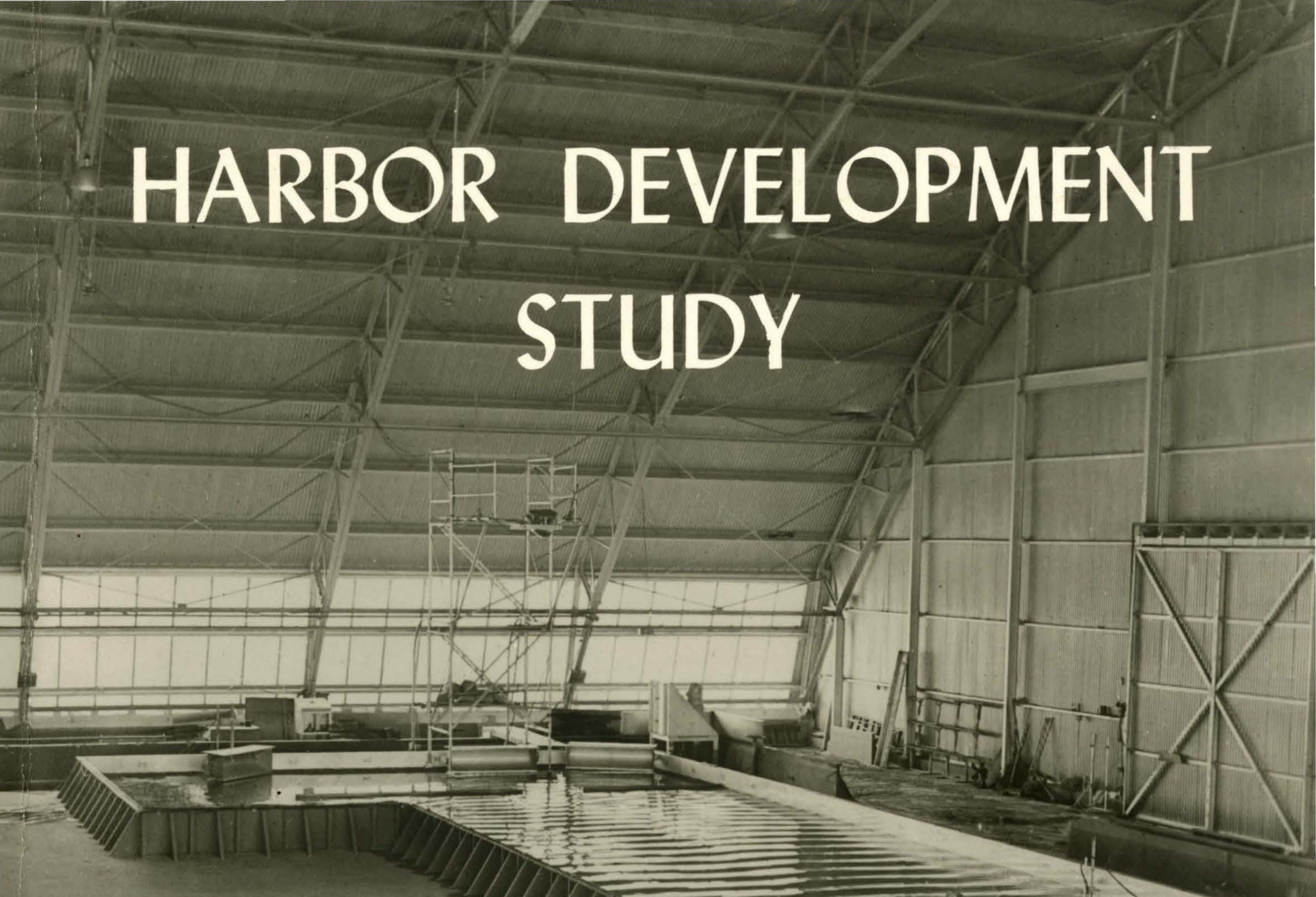
HARBOR DEVELOPMENT STUDY



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MODEL STUDIES FOR
HARBOR DEVELOPMENTS

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I. INTRODUCTION

The general objective of the Harbor Development Study is the investigation of the wave energy distribution in simple harbor areas, with the specific objective of determining design principles which will permit the prediction of harbor performance. The progress accomplished to date has consisted of the analysis of the problem in terms of applicable physical principles, the review of present knowledge of these principles, the formulation of a general laboratory program, and the construction of the laboratory facilities required for the first phase of the program. This report considers each of these items in turn.

II. FACTORS DETERMINING WAVE DISTURBANCE IN A HARBOR

Considered in the most general way, the level of wave energy at a point in a harbor is a function of two variables; the total amount of energy entering the harbor, and the distribution of energy within the harbor. Since these phenomena are at least partially unrelated, the investigation is naturally split into two phases, and the net results will be a synthesis of the two investigations. Also, since one or the other of these basic factors may be beyond the control of the designer for such reasons as navigational requirements, existing natural topography, budget or time limitations, etc., it is convenient to consider them separately.

Each of these factors is a boundary value problem, and in the following paragraphs of this section the important variables affecting each will be evaluated.

A. Transfer of Energy from Ocean to Harbor

The behavior of waves in the neighborhood of a breakwater gate may be analyzed by first considering the most simple case and then adding to this all foreseeable complications. Thus, consider a train of waves advancing with straight, parallel crests in an unbounded basin. If a perfectly absorbing breakwater with gate is placed in the path of these waves, we can expect, in the absence of any other factors, that a length of wave crest, equal to the projected width of the gate in the direction normal to wave advance, will be admitted to the protected region behind the breakwater. The portion of the wave train passing through the gate will have the original wave length and height. Since the energy per wave length of a wave train is proportional to the product of the square of the wave height and length of crest, we can write the following functional relation for the total energy entering the harbor per wave:

$$E = f\ (\ h^2\ w \cos\alpha\ ) \qquad (1)$$

where w is the gate width and α is the angle between the gate axis and the direction of wave travel.

The first complicating factor that must be considered is that of diffraction. If the spanwise equilibrium of a wave crest is being maintained by a physical boundary, and this support is removed (as when the inshore end of a wave crest travels along a breakwater and reaches the gate), spanwise equilibrium must be maintained by a movement of water parallel to the wave crest, or a spanwise propagation or extension of the wave crest. This is a diffractive process, and can account for an appreciable transfer of energy into the harbor, especially for cases where the wave crests are nearly perpendicular to the breakwater. This effect would appear to be a function of the angle between the approaching wave trains and the gate axis, the breakwater width, and the breakwater length (considering that the gate may be an entrance channel), or:

$$E = f\ (h^2 w \cos \alpha, \alpha\ , w, 1\ ) \qquad (2)$$

A second factor that must be considered is that of the reflection of waves incident on the breakwater near the gate. These reflections constitute a secondary wave train which may produce interference effects with the primary imposed wave train and so affect the incident wave energy. Also, the reflected waves may produce diffraction effects at the breakwater terminii which affect the incident wave trains. The net effect is difficult to predict, but is believed to be a function of the wave crest - breakwater angle, β , (which is the same as α only if the breakwater segments are parallel) and the gate dimensions, or:

$$E = f\ (h^2 w \cos \alpha, \alpha\ , w, 1, \beta\ ) \qquad (3)$$

The effect of offshore topography, which may introduce refraction, is not considered a proper part of the general study, since if the offshore bottom topography is only mildly irregular the only effect is to determine the final wave crest alignment at the breakwater, which is already defined as α, and if grossly irregular the bottom shore topography may have such an overpowering effect as to be considered a subject for special study. A limited number of such gross bottom irregularities may be investigated in the current program to indicate the order of magnitude of effects that may be expected in such cases.

From the above discussion, it is apparent that at least the following variables must be considered in the study of wave energy transfer into a harbor:

1. Alignment of gate relative to approaching wave crests.
2. Gate dimensions.
3. Breakwater reflection coefficient.
4. Breakwater arm alignment.

B. Energy Distribution Within a Harbor

The alignment of the primary wave trains within a harbor, and hence the distribution of energy associated with these waves, is determined by the processes of refraction and diffraction. When the primary waves reach basin boundaries they may be reflected and so generate a secondary wave system, and the alignment of this secondary wave train will in turn be affected by diffractive and refractive processes. The net vertical water motion or energy level in different parts of the harbor will be the result of the interaction of the two wave trains producing a characteristic standing wave pattern superimposed on the primary wave train.

In so far as the diffractive process is concerned, the distribution of primary wave energy will depend to some extent on the factors previously discussed in relation to the process of energy transfer into a harbor, notably the wave crest - gate axis alignment and the gate width. In addition, the energy distribution due to diffraction is a function of size and shape of the harbor and the relative location of the gate.

Refraction is a result of non-uniform water depth, and the process is such that the wave crests tend to become parallel to the bottom contours. The energy distribution due to refraction will therefore depend on the bottom topography of the harbor, the location of the gate or source of primary wave energy, in relation to the bottom topography, and the size and shape of the harbor.

The amplitude of the secondary wave train will depend on the reflection coefficients of the harbor boundaries and the local incident wave amplitude - hence on the distribution of primary wave energy. The alignment of the secondary wave crests will depend on the relation between the basin boundaries and the primary wave crest alignment, or in general, on the basin size and shape and all of the previously enumerated factors affecting the distribution of primary wave energy. It should be emphasized that in regions near good reflecting surfaces, such as sheet-pile bulkheads, the secondary or reflected wave energy is as important as the primary wave energy.

The distribution of wave energy within a harbor, as noted in the introductory paragraph of this section, is best considered as a separate problem, with the actual physical level of disturbance at a point in the harbor determined from the knowledge of this distribution and the total amount of energy entering the harbor, which in turn is a function of harbor entrance design and the particular ocean conditions.

III. PRESENT STATE OF KNOWLEDGE

A. Diffraction

The phenomenon of diffraction of surface waves by barriers has only recently been studied. The investigation of this process has been stimulated by the realization that certain problems in optics for which theoretical solutions have been obtained are analogous to the problem of the diffraction of surface waves. Thus, PENNEY and PRICE [1] have shown that SOMMERFIELD'S [2] solution of the diffraction of light by a semi-infinite screen where the light is polarized in a plane parallel to the edge of the screen, is also a solution of the water-wave diffraction problem for a semi-infinite breakwater.

PUTNAM and ARTHUR [3] have obtained numerical values for this case and have performed experimental confirmations for certain simplified cases. BLUE and JOHNSON [4] apply the foregoing theory to diffraction by breakwater gates by superimposing the solutions for two semi-infinite breakwaters, one extending in the x-positive and the other in the x-negative direction, with origins separated by the gate width. This method is valid only for gate widths several times the imposed wave length. They present experimental data in substantial agreement with the theory for a limited number of conditions.

These studies constitute a good background of knowledge of diffraction although the following important factors are either not considered or are not sufficiently investigated.

1. Diffraction effects for gates of less than one wave length in width.

2. Effects due to diffraction of waves reflected from the seaward face of the breakwater.

3. Effect of diffraction on increasing the net energy transfer into a harbor.

B. Refraction

The phenomenon of wave refraction is well understood as the result of wave forecasting investigations performed during the recent war. Refraction is a much simpler process than diffraction, being primarily a function of change in wave velocity due to changing water depth. Simple graphical techniques for the solution of refraction problems are given in reference (5).

C. Reflection

Reflection is not so much a source of aberration of the incident wave train as it is a generator of a secondary wave train, and the effects of reflection are best considered in this way. Two recent model investigations which consider the importance of reflection in producing the net water surface disturbance in a particular area are described in references (6) and (7).

D. Synthesis of Physical Processes

No attempt has been made to consider the combined effect of any of the above mentioned three processes which determine wave energy distribution. Considering refraction and diffraction only, it is not known if results determined independently can be combined linearly, or if a composite investigation must be made for each combination of significant boundary conditions. The effect of reflection in combination with the other two factors is easier handled, since reflection gives rise to a new wave train, and the two wave trains may be readily superimposed.

E. References

(1) PENNEY, W. G. and PRICE, A. T. "Diffraction of Sea Waves by Breakwaters", Directorate of Miscellaneous Weapons Development History No. 26, - Artificial Harbors, Sec. 3D, 1944.

(2) BATEMAN, H. Partial Differential Equations of Mathematical Physics, Dover, 1944.

(3) PUTNAM, J. A. and ARTHUR, R. S. "Diffraction of Water Waves by Breakwaters", Transactions, American Geophysical Union, Vol. 29, No. 4, 1948.

(4) BLUE, JR., FRANK L. and JOHNSON, J. W. "Diffraction of Water Waves Passing Through a Breakwater Gap", Transactions, American Geophysical Union, Vol. 30, No. 5, 1949.

(5) FLUID MECHANICS LABORATORY. "Graphical Construction of Wave Refraction Diagram", University of California, Berkeley, Calif., 1946.

(6) HYDRAULIC STRUCTURES LABORATORY. "Wave and Surge Study for the Naval Operating Base, Terminal Island, Calif.", California Institute of Technology, Pasadena, Calif., 1945.

(7) HYDRAULIC STRUCTURES LABORATORY. "Model Studies of Apra Harbor, Guam, M.I.", California Institute of Technology, Pasadena, Calif., 1949.

IV. FORMULATION OF LABORATORY PROGRAM

The great danger in planning a laboratory program for an investigation such as this is that the number of variables is so large, and the range of each variable so great, that a purely testing program to cover every item in detail would be of nearly infinite duration. Every effort must be made, therefore, to concentrate on developing general principles instead of specific data, and wherever possible, on rigorous analytical derivation of these important principles. However, a logical sequel to, or sub-aim of this project may well be the verification of such general principles as applied to a particular prototype problem.

A. Investigation of the Transfer of Energy into a Harbor

1. Object: Determine the effect of gate axis-wave crest alignment and gate dimensions on energy admitted through a breakwater gap.

a) Constants: Vertical-face breakwater; straight breakwater alignment; depth of water at breakwater (50 ft.).

b) Variables: Gate axis-wave crest alignment, 0° to 90°; gate widths, ½, 1 and 2 wave lengths; wave periods, 10 and 15 sec.

c) Technique: Determine wave crest alignment immediately inside breakwater gate, position wave height measuring elements along this alignment and integrate the resulting measurements to obtain the total energy admitted for the particular conditions studied.

2. Object: Determine the modifying effect on the results of (1) of a partially reflecting (rubble mound) breakwater.

a) Technique: Repeat a few of the measurements made in (1) with rubble mound breakwater.

3. Object: Determine the modifying effect on the results of (1) of breakwater arm inclined at 90° and 135°.

4. Object: Determine the modifying effect on the results of (1) of an entrance channel one or two wave lengths long.

B. Investigation of the Distribution of Energy Within a Harbor

1. Object: Determine the effect of basin shape and gate location on the distribution of wave energy due to diffraction.

a) Constants: Gate width (one wave length); wave period (10 sec.); basin area; absorbing basin boundaries.

b) Variables: Proportions of the idealized rectangular basin (1:1, 1:3, 1:5); gate position, (center of long and short sides); wave crest-gate axis alignment (0°, 45°, 75°).

c) Technique: Determine wave energy distribution by photographing wave crest alignment and measuring wave amplitude with conductivity elements.

2. Object: Determine the modifying effect of refraction on the results of (1) above for two extremes of typical harbor bottom topography (dish- shaped and fiord types).

3. Object: Determine the effect of local reflecting basin boundaries on some of the results of (1) and (2) above.

4. Object: Demonstrate the advantages obtained by predicting diffraction, refraction and reflection effects in harbor design.

a) Technique: Design a hypothetical harbor for an open shelving coast location on the basis of the foregoing work and evaluate the design by model verifications.

This admittedly ambitious program will undoubtedly be modified and possibly curtailed, but it represents the present aims of the Laboratory and in most respects seems to be the minimum program to achieve the desired results.

V. PHYSICAL PROGRESS

The physical progress accomplished to date consists of the preparation of laboratory facilities necessary for the first phase of the investigation - the study of the transfer of wave energy from the ocean into a harbor. The major facility is a test basin located in the southeast corner of the Laboratory which incorporates a generalized coastal construction, consisting of a horizontal inshore area and an offshore slope of 1 : 40. A fixed wave generator is located at the deep end of the basin. Movable breakwater sections provide a convenient method of adjusting gate axis-wave crest alignment. Wave absorbing gravel beaches which are readily adjusted for different breakwater alignments prevent unwanted wave reflections from the basin walls. Fig. 1 shows the inshore area of the basin. A detailed description of the basin and major auxilliary equipment follows:

Test Basin

The basin is L-shaped, the part containing the offshore slope construction being 20 ft. wide and 36 ft. long. The contiguous portion containing the inshore construction is 32 ft. wide and 24 ft. long. The purpose of the offset portion of the inshore region is to provide room for an absorbing beach to receive the waves reflected from the breakwater when the breakwater is rotated to provide acute incident angles. The basin walls are formed of the portable metal wall sections developed for the Guam study. The coastal construction consists of a rock dust fill vibrated in place while wet, capped with a 1 inch thick layer of concrete. Fig. 2 shows the stages of construction of the test basin. For a prototype harbor depth of 50 ft., a convenient scale ratio of 1 to 240, or 1 inch = 20 feet results in a laboratory water depth of 2½ inches for the inshore area. With this scale, the wave generator is located 1.7 miles from the breakwater gate, where the prototype depth is 240 feet. The small basin water volume, 600 cu.ft., permits use of the domestic water supply for filling; drainage is to the laboratory peripheral trench and thence to underground storage.

Photographic Facilities

An overhead camera position is obtained by means of a modified commercial scaffold which was available in the Laboratory. This scaffold is constructed of light weight aluminum tubing and is in the form of a tower and cantilever platform. Modifications include an extension to the platform to accommodate a K-17 aerial camera, a safety railing around the platform and rope stays to increase the stability of the system. Fig. 3 shows this camera tower. The distance from camera to water surface is 14 feet,

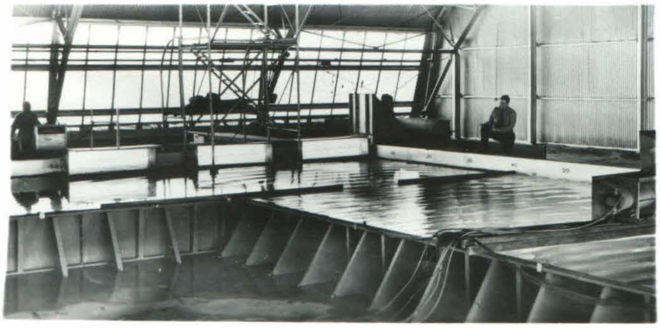

Fig. 1 - Basin with test breakwater in place

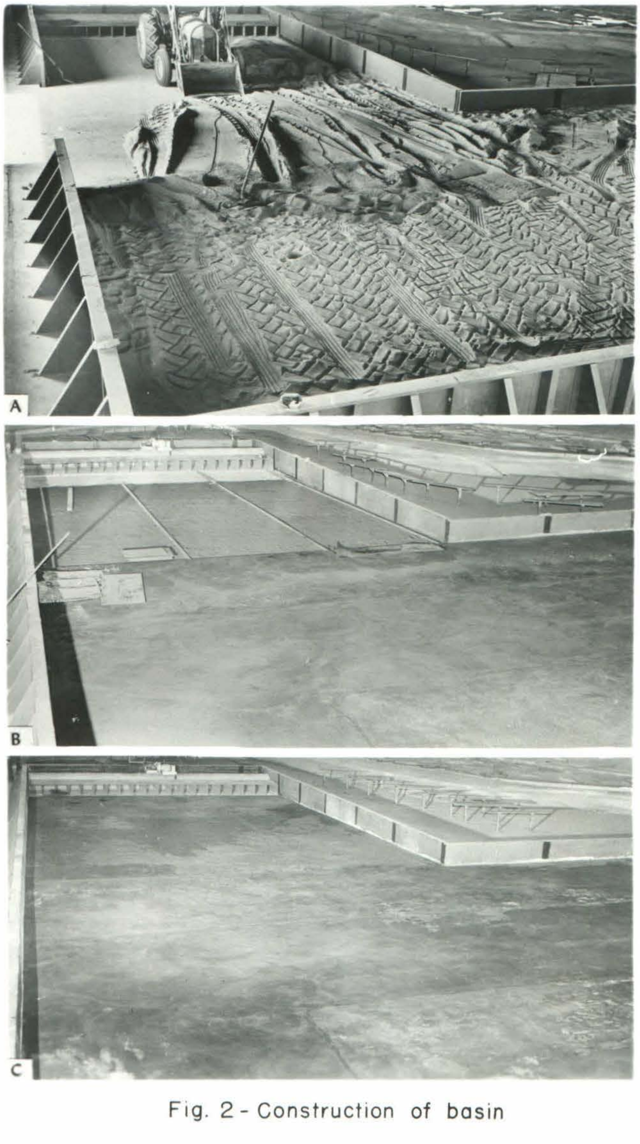

Fig. 2 - Construction of basin

(a) Placing rock dust fill

(b) Finished sub-grade with screeds in place for concrete cap

(c) Partially completed concrete cap

Fig. 3 - Camera tower

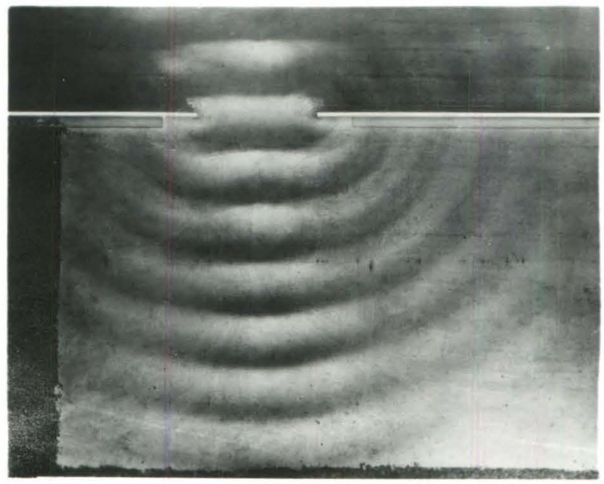

Fig. 4 - Wave pattern

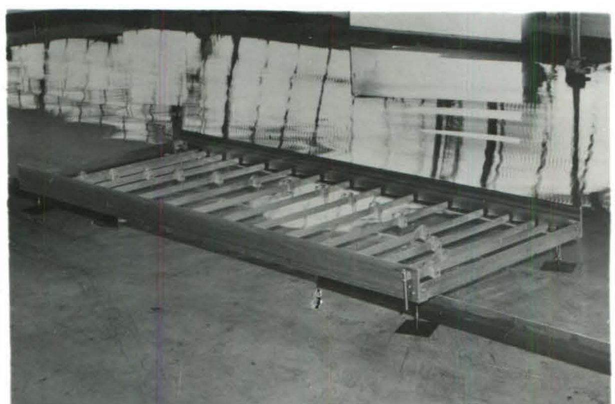

Fig. 5 - Element rack in place in test basin

new camera lens spacers being made for this distance. The field of view with the 6 in. Metrogon lens is 20 ft. by 20 ft., hence covers essentially all of the inshore area. Photographic illumination is provided by the Edgerton flash lamp system used in the Guam study. Fig. 4 is a typical wave pattern photograph.

Wave Height Measurements

Wave height measurements will be made by means of electrical conductivity probes essentially the same as those used in the Guam study. In order to position the measuring elements along a wave crest alignment, a supporting framework of aluminum angles has been made. This frame has a levelling screw at each corner, and has provision for mounting transverse 3/4 in. by 1 in. aluminum angles at 2 inch intervals. A measuring element may be positioned at any point on each transverse member. This device is therefore a coordinate system in which measuring elements may be fixed to trace out the curve of wave alignment. Fig. 5 shows 15 wave elements in position at the breakwater gate.